Renewable and Sustainable Energy Reviews 15 (2011) 4483–4490

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A review on the experimental and analytical analysis of earth to air heat exchanger (EAHE) systems in Turkey

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ARTICLE INFO

Article history:
Received 29 March 2011
Accepted 5 July 2011
Available online 15 September 2011

Keywords:
Energy analysis
EAHE
Exergy analysis
Exergoeconomic
Geothermal
Solar
Renewable energy
Turkey

ABSTRACT

During the last three decades, a number of studies have been conducted by various investigators in the design, modeling and testing of earth to air heat exchanger (EAHE) systems. This paper reviews the studies conducted on the experimental and analytical analysis of EAHE systems in Turkey and around the world as of the end February 2011. The studies undertaken on the EAHE systems are categorized into two groups as follows: (i) open loop for space heating/cooling and (ii) closed loop for space heating/cooling systems. This paper investigates the studies on EAHEs, also known underground air tunnel systems.

Contents

1. Introduction

The idea of using earth as a heat sink was known in ancient times. In about 3000 B.C., Iranian architects used wind towers and underground air tunnels for passive cooling [1,2]. Underground air tunnels (UAT) systems, nowadays also known as earth to air heat exchangers (EAHEs), have been in use for years in developed countries due to their higher energy utilization efficiencies compared to the conventional heating and cooling systems. EAHE is a passive climate control technique that has application in residential as well as agricultural building utilizes the underground soil temperature that stays fairly constant at a depth of about 2.5–3 m [2,3].

Abbreviations: COP, coefficient of performance; CFC, chlorofluorocarbons; EXCEM, exergy cost energy and mass; EAHE, earth to air heat exchanger; GSHPs, ground-source heat pumps; GSHPS, ground-source heat pump system; ISAHP, integral-type solar assisted heat pump; PVs, photovoltaics; TRT, thermal response test; UAT, underground air tunnel systems; UEAHESGHPA, utilization of earth air heat exchangers for solar greenhouses pre heating and performance analysis.

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1364-0321/$ – see front matter
doi:10.1016/j.rser.2011.07.103

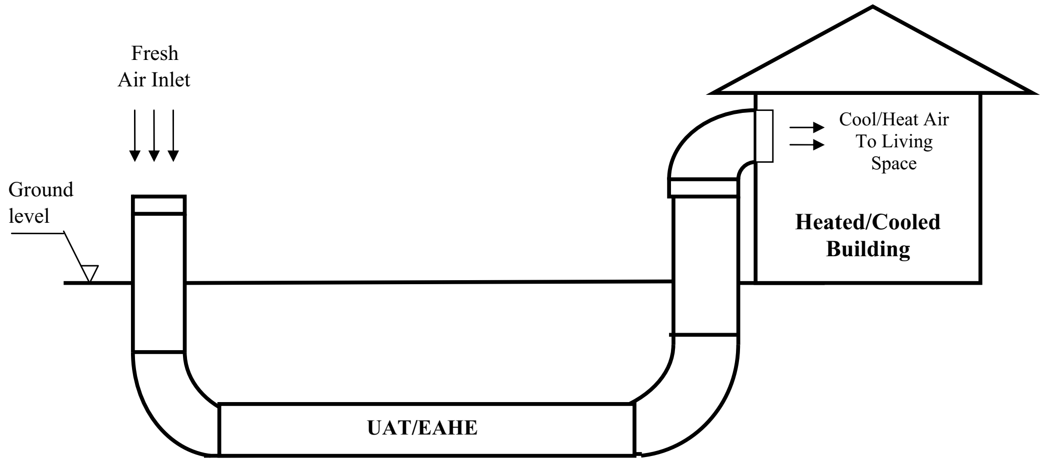

Fig. 1. Schematic of open loop EAHE (underground air tunnel).

The energy performance of an EAHE system can be influenced by three primary factors: the EAHE pipe material, the circulating fan, and the soil characteristics and moisture content [1–43]. Knowledge of soil thermal properties is very important in the design and application of this technique [3–5,12,14–20].

EAHEs have been used for many years for both space pre heating and pre cooling; however, their efficiency is influenced by the variation in outside temperature. When heat is most needed, the outside air is cooler, thus often requiring backup electric resistance heating during the coldest days. Similarly, cooling is needed during the hottest days, requiring the equipment to work at low efficiencies.

Overcome the problem of resource variations, as ground temperatures remain fairly constant throughout the year. Depending upon the soil type and moisture conditions, ground (and groundwater) temperatures experience little if any seasonal variations below about 10 m [2].

The EAHE thus have several advantages over air source heat pumps, integral-type solar assisted heat pump (ISAHP) and GSHPs [44–53]. These are:

- They consume less energy to operate,
- It is expected that air pollution problems will be minimized by using EAHEs for passive cooling and heating purposes,
- In Mediterranean and tropical regions, they do not require supplemental heat during extreme low outside temperature,
- They do not use compressor, CFC, or any refrigerant,
- Air uses as working fluid in EAHE,
- They have a simpler design and consequently less maintenance,
- They do not require the unit to be located where it is exposed to weathering,
- They have lower initial cost than GSHPs and ISAHP.

The main disadvantages of EAHEs,

- EAHEs are the higher initial cost, being about 20–40% more expensive than air source units under Turkey conditions. This is due to the extra expense and effort to bury heat exchangers in the earth or providing a sink for the energy source. However, once installed, the annual cost is less over the life of the system, resulting in a net savings. The savings is due to the coefficient of performance (COP), averaging over 3 for EAHE and GSHP as compared 2 for air-source heat pumps and ISAHP [28–33,54–57].
- Second disadvantage of EAHE is convection of fan noise via pipes to the far away living space.
- Third disadvantage of EAHE is air vapor condensation discharge from EAHE. Useful solution for solving condensed water vapor discharge problem in the underground air tunnel, there is a way to pump out any water in the pipe, that is, a small submersible pump is located at the lowest point. However, this solution will increase total energy consumption of the system. It is expected that sum of the total COP value of the system will decline [29].
- Fourth disadvantage of EAHE is during the operating period working fluid (air) quality decreases and possibility of fatal microorganisms cultivate, so proper filter should be used or air quality should be monitored strictly by operators.

One of the first steps in the consideration of an EAHE system is a characterization of the site in terms of geology availability. Information concerning aquifer (or aquifers) available at the site, their ability to produce water, depth to water, geology, depth to bedrock and the nature of the soil and rock (hydraulic and thermal properties) are key issues. This information guides the designer in the selection of the type of GSHP or EAHE system to be used and in the design of the system [1–43].

Two major types exist: open loop EAHE (Fig. 1) or closed loop EAHE (Fig. 2). The ground coupled uses a buried earth coil with circulating air in a closed loop of horizontal or vertical pipes to thermal energy to and from the earth.

The structure of the paper is as follows. The first section includes the introductory part; Section 2 gives a brief information about historical background of EAHE, Early studies conducted on experimental and analytical analysis of EAHE in the world are investigated in the third section; Section 4 conducted on EAHE systems at the Turkish universities, and the last section concludes.

2. A brief of historical background of EAHE in the world

In tropical climates, air conditioning is widely employed not only for industrial production but also for the comfort of occupants. It can be achieved efficiently by vapor compression machines, but due to depletion of ozone layer by chlorofluorocarbons (CFCs) and the need to reduce high grade energy consumption; numerous alternative techniques are being currently explored. One such proposition is the earth air pipe system. It uses soil as a heat sink and air as the heat transfer medium for space cooling summer. When the warm air flows in the earth air pipes, heat is transferred from air to the earth. As result, the air temperature at the outlet of the earth air pipes is much lower than that of the ambient [41].

As mentioned earlier, the idea of using earth as a heat sink was known in ancient times. In about 3000 BC, Iranian architects used wind towers and underground air tunnels for passive cooling [2,8]. In 19th Century Wilkonson [21] designed a barn for 148 where a

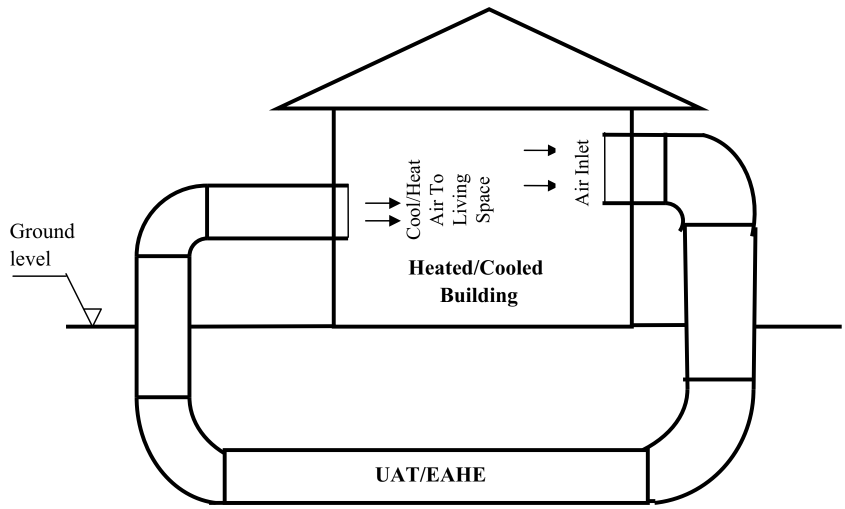

Fig. 2. Schematic of closed loop EAHE (underground air tunnel).

500-ft long underground passage was used for cooling during the summertime. From the middle of the twentieth century, a number of investigators have studied the cooling potential of buried pipe [2].

Since that time, a number of experimental and analytical studies of this technique have appeared in the literature [1–21,28–43]. Goswami and Dhaliwal [5] gave a brief review of the literature. In their paper, they presented an analytical solution to the problem of transient heat transfer between the air and surrounding soil as the air is made to pass through a pipe buried underground. Goswami and Ileslamlou's paper [2], the work of Goswami and Dhaliwal [5] was extended to analyze a closed loop air conditioning system using an underground air tunnel. The usefulness of this method was studied by analyzing the COP of the system. This study shows that using the system, the soil temperature around the pipe increases, causing limitation in technique.

Till 2001, about 1000 passive house units have been built in Germany and this amount sensibly doubles every year [58]. In Europe, already more than 5000 passive house units have been successfully built and completed [59].

2.1. Current status and future directions of EAHE in Turkey

The concept of EAHE is not new. However, the utilization of EAHEs in residential and agricultural buildings is new in Turkey, although they have been in use for years in developed countries and the performance of the components is well documented. The study only carried out on EAHE in Turkey as university research studies. In addition, solar building and EAHE technologies commercially available are not yet well known by the architects, so EAHEs have not been put on the Turkish market. The first experimental installation was realized in 2009 with a total design heating capacity of 5 kW, representing a total floor area of 10 m^2 [4,6,28–33]. There are no Turkish EAHE's designer and manufacturers yet. According to author's foresight, the majority of the installations can be applied in the all regions of Turkey, yet first installation development can be started from Marmara region (in the province of Istanbul). High-income earners also prefer these systems. Design practices in Turkey normally call for U-bend depths between 11 and 13 m/kW of heating. The ground loop constitutes approximately 24–26% of the total system costs in the installations in the country. Therefore, care must be taken in the design and construction of a ground loop for an EAHE application to ensure long ground loop life and reduce the installation costs [54,60].

A significant European development in this frame was the adoption of the Directive 2002/91/EC [61]. Following this directive, Member states are gradually applying minimum requirements on the energy performance of new buildings and large existing buildings that are subject to major renovation. Energy certification of buildings is based on the above as well as the regular inspection of heating, ventilation and air conditioning systems [62]. This is because EAHEs can be preferred as energy saving method in buildings, in Turkey. The primary barrier to marketing EAHE systems in Turkey is, however, the incremental cost of installing ground heat exchangers, which makes the total investment higher. Author believe that the utilization of EAHS and its contribution to the economy of Turkey has been increased from day to day.

3. Early studies conducted on experimental and analytical analysis of EAHE in the world

The optimization of thermal systems cannot be always carried out using mathematical or numerical optimization techniques, due to incomplete models, plant complexity, or generic difficulties in the mathematical treatment. Furthermore, mathematical or numerical optimization simply applies to one specified structure of the system whereas, often, structural modifications would be able to improve the cost effectiveness of the plant. Nevertheless, is not always possible or practical to develop a mathematical model for every promising design configuration of a system [63].

Various design tools have been developed for the determination and evaluation of thermal properties of borehole heat exchangers by many researchers. Mogensen [22] presented thermal response test (TRT), which has been used as a very effective method to determinate the ground thermal conductivity. Rottmayer et al. [23] studied the performance of a single borehole by applying finite difference method to both the interior of a single borehole and the surrounding ground using cylindrical coordinate system and neglecting heat conduction in vertical direction. Lee and Lam [24] improved a computer simulation of borehole ground heat exchangers for geothermal heat pump systems. Yu et al. [25] enhanced a simplified model for measuring thermal properties of deep ground soil. Lee and Lam [24], Yu et al. [25], Bose [26], Zeng et al. [27], Goswami and Ileslamlou [2], and Goswami and Dhaliwal [5] etc. described borehole heat resistance (R_0) models in their studies.

Ozgener et al. [4,33] defined total heat resistance of an earth air heat exchanger, which was installed by at the Solar Energy

Institute of Ege University (latitude 38.24N, longitude 27.50E), Bornova, Izmir, Turkey [4–6,28–33].

The heat transfer from pipe to soil is analyzed by considering the heat flux at the internal radius of a semi infinite cylinder formed by the soil around the pipe [12].

Many experimental studies have reported various types of UAT which are summarized by [28–33,64,65] studied the heating and cooling performance of UAT. Ghosal and Tiwari [65] and Ghosal et al. [64] reported the modeling of an earth to air heat exchanger with a greenhouse. Goswami and Ileslamlou [2] studied the performance analysis of a closed loop climate control system using underground air tunnel system. Numerical simulation, technical and economic evaluation, and aspects of air-to-earth heat exchangers was investigated by Bojicǐ et al. [66]. They used the same structure both heating and cooling applications. They found the cost of the EAHE energy is lower for summer than winter. Badescu [59], Mihalakakou et al. [36], Wu et al. [41], Ozgener and Ozgener [28–32] studied the cooling potential and performance evaluations of earth to air heat exchangers. Ozgener and Ozgener [28–32] reported exergetic and exergoeconomic performance of an underground air tunnel system for greenhouse heating and cooling.

Scott et al. performed a study on steel pipe buried underground [1,5]. Their experimental results were useful in showing the potential of such systems [5]. Glennie et al. [6] presented a computer simulation to calculate the cooling available on a particular average day of month [5]. Abrams et al. [67] also presented a theoretical model for this problem and compared their results with experiments [5]. Smilarly, Nordham [9], Bircher [10], and Sinha [11] presented investigations but none can be called complete as in some of them the experimental results were uncertain while in others there were limitations in theoretical models [5].

Bojic et al. [66,68] evaluated the technical and economical performances of EAHE. In addition, Bojic et al. [68] investigated about EAHE with using steel and PVC pipes. They divided the soil and pipes into elementary volumes to obtain the mathematical equations [68].

Ghosal et al. developed a simplified analytical model to study year around effectiveness of an EAHE coupled greenhouse located in New Delhi, India. They found the temperature of greenhouse air on average 6–7 °C more in winter and 3–4 °C less in summer than the same greenhouse when operating without EAHE [65].

Ghosal and Tiwari developed a new thermal model for greenhouse heating and cooling with EAHE in New Delhi, India. It was found on average 7–8 °C higher in the winter and 5–6 °C lower in the summer than those of the same greenhouse without EAHE. They showed that greenhouse air temperature increased in the winter and decreased in the summer with increasing pipe length, decreasing pipe diameter, decreasing mass flow rate of flowing air inside buried pipe and increasing depth of ground up to 4 m [64].

Chel and Tiwari used EAHE integrated adobe structures for New Delhi composite climate. They investigated about performance evaluation and life cycle cost analysis of EAHE. The authors found temperatures 5–15 °C higher or lower as compared ambient values and payback period less than 2 years [69].

Bansal et al. [70] investigated the performance analysis of EAHE for summer cooling in Jaipur, India. They discussed 23.42 m long EAHE at cooling mode in the range of 8.0–12.7 °C and 2–5 m/s flow rate for steel and PVC pipes. They showed performance of system is not significantly affected by the material of buried pipe instead it is greatly affected by the velocity of air fluid. They observed COP variation 1.9–2.9 for increasing the velocity 2–5 m/s [70]. Chel and Tiwari realized space heating and cooling with an EAHE integrated stand alone photovoltaic system in New Delhi, India. The authors measured annual performance evaluation and showed energy payback time and unit cost of electricity [71].

Tittelein et al. [47] realized theoretical studies about earth to air heat exchangers and specified them as a numerical model or an analytical model. Bandyopadhyay et al. [72] offered analytical solutions for short time transient response of ground heat exchangers and showed that borehole boundary temperature data can be analyzed for measurements of thermal conductivity of medium in thermal response tests.

Maerefat and Haghighi [73] investigated about passive cooling of buildings by using integrated earth to air heat exchanger and solar chimneys for hot seasons. Zhang and Haghighat [43] developed an artificial neural network based heat connection algorithm for thermal simulation of large rectangular cross-sectional area earth-to-air heat exchangers. They showed a new method can simulate the interactions between a heat exchanger and its environment. Florides and Kalogirou [40] presented a review of ground heat exchangers systems, models and applications. They explained several types and several calculation models for ground heat exchangers. Pfafferott [37] presented a study about evaluation of earth-to-air heat exchangers with a standardized method to calculate energy efficiency. The author studied about temperature behavior, energy gain, general efficiency and thermal efficiency. Thiers and Peuportier [74] studied about thermal and environmental assessment of a passive building equipped with an earth-to-air heat exchanger in France.

4. Studies conducted on EAHE systems at the Turkish universities

The first experimental study on EAHE was launched in June 2009. The project entitled Utilization of Earth Air Heat Exchangers for Solar Greenhouses pre Heating and Performance Analysis (UEAHESGHPA) in the Ege University Project No: 09GEE003. UEAHESGHPA is demonstration project for exploring the potentials of a particular GHE design for providing thermal energy to meet space heating/cooling requirements for greenhouses in different regions of Turkey throughout the year.

Although various studies were undertaken to evaluate the performance of underground air tunnel, as described previously, to the best of author's knowledge, no studies on the energetic, exergetic, and exergoeconomic analysis of an underground air tunnel with a 47 m, 56 cm nominal diameter U-bend horizontal galvanized ground heat exchanger for greenhouse heating/cooling have appeared in the open literature under Turkey's conditions [4,6,28–33]. In addition this project was enhanced with solar photovoltaic cells in 2010. Currently, investigations go on monitoring of performance analysis of. Solar photovoltaic cell (PV) assisted earth to air heat exchanger (under ground air tunnel) system for greenhouse heating/cooling [6].

A schematic diagram of the constructed experimental system is illustrated in Fig. 1. This system mainly consists of six separate circuits: (i) the converter, (ii) the 0.9 kW PV cells, (iii) the inverter, (iv) the fan (air blower) circuit for greenhouse cooling, (vi) the ground heat exchanger (underground air tunnel or EAHE), (vii) greenhouse. The main characteristics of the elements of the system are given in Table 1. The PV assisted EAHE system studied was installed at the Solar Energy Institute of Ege University (latitude 38°24′ N, longitude 27°50′ E), Izmir, Turkey. Solar greenhouse was positioned towards the south along south-north axis. The greenhouse will be conditioned during the summer and winter seasons according to the needs of the agricultural products to be grown in it. Fig. 1 shows a schematic of the system which utilizes an underground galvanized pipe in combination with a blower to keep the greenhouse temperature at the set condition. A positive displacement type of air (twin lobe compressor) blower of 736 W capacity and volumetric flow rate of 5300 m^3/h was fitted with the

Table 1
Main characteristics and technical specifications of the system [4,6,28–33].

Element	Technical specification		
Earth to air heat exchanger (underground air tunnel)	Horizontal U-bend type (closed loop), buried pipe diameter: 56 cm, 47 m long; greenhouse connection pipe diameter 80 cm, 15 m long		
Blower (Fan)	Volumetric air flow rate 5300 m^3/h at 200 KPa; the rated power of electric motor driving 736 W		
Greenhouse	Glass reinforced plastic surface 48.512 m^2		
Photovoltaic specifications	Issue	6	Piece
	Dimensions	1344*789*72	Mm
	P_{m}	150	Watt
	V_{m}	30.6	Volt
	I_{m}	4.87	Ampere
	V_{oc}	36.9	Volt
	I_{sc}	5.47	Ampere
	Polycrystalline	IEC 61215	IP 65
	Type	Axitec	
Inverter	DC to AC Power inverter 1000 W		
	24 V_{dc} to 230 V_{ac} 50 Hz		
	Type	Koselli (Akowa)	
Converter	AC to DC (PSP 1000)		
	Input	220–240 V_{ac}	7A
	Output	24 V_{dc}	37A
	Type	Meanwell	
Air blower	Voltage	220	Volt
	Cos φ	1	–
	Power	736	Watt
Network analyzer	V_{in}	10–500 V	46–65 Hz
	I_{in}	0.05–5.5 A	
	Class	1%	±1 digit
	Type	Entes	MPR53
Pyranometer	Sensitivity	4.5×10^{-6}	V per W/m^2
	Model	CM11	
	Type	Kipp & Zonen	
Anemometer	Range 0.5–40 m/s	Resolution 0.01 m/s	Accuracy ±2%
	Operating	0–50 °C	80% RH
	Type	Lutron	AM-4206M
PT 100 Resistant Thermometers	Resistance	100 Ω at 0 °C	
	Class	1.5%	
	Type	Elimko	
Temperature and relative humidity transmitter	Temperature range	−20 to +70 °C	±0.5 °C
	Relative humidity range	0–100%	±2.5%
	Sensitivity	0.1 °C	0.1%
	Voltage	24 V_{dc}	IP 65
	Type	Testo	6621-A02
Data Logger	Class	0.5	9 digit
	Analog to digital conversion	16 bit	
	Digital to analog conversion	12 bit	
	Working conditions	−5 to 55 °C	85–265 V_{ac}
	Type	Elimko 680	

suction head positioned in the southwest corner of the greenhouse [4,6,28–33].

4.1. Heating performance studies of EAHE

In the present study, the results were obtained from the experiments over the heating period of 9 October 2009 through 10 October 2009, were evaluated to determine the overall COP, exergetic efficiency, and some exergoecomic parameters of the system. During the experimental period, the average value of the temperature and the relative humidity for the greenhouse were obtained to be 21.5 °C and 40%, respectively. The average aspiration air flow rate was found to be 469.36 m^3/h per kW of heating, with a circulating power of 95.17 W/kW of heating. The average entering air temperature to the EAHE over this the period was approximately 18.67 °C, while the average entering relative humidity to EAHE over the period was about 48.16%. The average temperature difference of the air between the inlet and outlet of the underground air tunnel was obtained to be approximately 6.09 °C. The average heating capacity of the system was determined to be 7.67 kW for this experimental period. The temperature of the air and the pipe surface at various lengths of pipe, the inlet and outlet temperatures of the air were recorded by data logger at 1 min intervals for 12 h at October 9, 2010 night [28,30,32].

4.2. Cooling performance studies of EAHE

After starting the system, the maximum cooling capacity of the underground air tunnel system occurred at approximately 3:00 PM. For example, the maximum cooling power of 11.54 kW could be realized at 3:00 PM for the buried pipe with the radius of 0.28 m, and the daily maximum cooling coefficient of performances (COP) values for the system are also obtained to be 15.8. The total average COP in the experimental period is found to be 10.09. The system COP was calculated based on the amount of cooling produced by the air tunnel and the amount of power required to move the air through the tunnel, while the exergetic efficiency of the air tunnel is found to be in a range among 57.8–63.2%. The overall exergy efficiency value for the system on a product/fuel basis is found to be 60.7% [29,31].

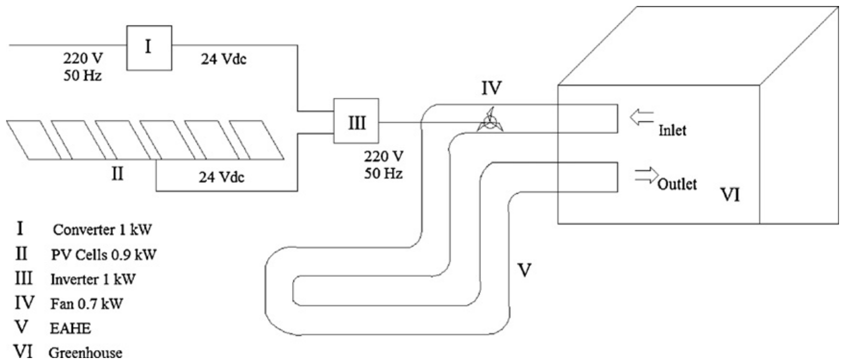

Fig. 3. Schematic of experimental set up of the PV assisted closed loop EAHE [6].

4.3. Exergoeconomic studies of EAHE

The author also has extended their studies to perform an exergoeconomic analysis [29,32] using the exergy, cost, energy and mass (the so-called: EXCEM) approach [57]. This approach involved examining data for devices in the EAHE, and showing that correlations existed between capital costs and specific second-law-based thermodynamic losses (i.e., total and internal exergy losses). The existence of such correlations likely implies that designers, knowingly or unknowingly, incorporate into their work the recommendations of exergy analysis.

4.4. Experimental prediction of total thermal resistance of a closed loop EAHE

The design of an earth to air heat exchanger (EAHE) requires knowledge of its total thermal resistance (R_{Tot}) for heating and cooling applications. Based on the experimental results, generalized relationships were developed for predicting of thermal resistance of the heat exchanger. Average total heat exchanger thermal resistance was estimated to be 0.021 K-m/W as a constant value under steady state condition [33].

4.5. Soil temperature variations with time and depth

Soil temperature fluctuates annually and daily affected mainly variations in air temperature and solar radiation. The soil temperature at 3 m depth is strictly recorded during experimental studies. The data was recorded by using Elimko E-680 data logger. E-680 series universal data loggers are new generation micro-controller based instruments compatible with IEC (International Electrotechnical Commission) 668 standards. E-680 series indicate measurements from 32 different points on instrument display and determines alarm conditions according to the result of comparison of two set points for each channel. The instruments can be connected to an RS-485 communication line and the data can be collected and stored in a centrally located PC. It has a resolution of 0.1 °C, 1 W/m^2 for temperature and solar radiation, respectively, and its accuracy of 0.5% The soil at site was a mixture of clay, sand and small rocks. A sample of the soil taken from 3 m depth was tested for thermal properties. Thermal conductivity was estimated to be 2.850 W/mK [4,6,28–33].

Temperatures of air, galvanized pipe surface, and soil at different locations were measured using PT-100 resistant thermometers. The temperatures of the air were measured at distances of 0 m, 4.2 m, 8.4 m, 12.6 m, 16.8 m, 21.2 m, 25.6 m, 29.8 m, 34 m, 38.2 m, 42.4 m, and 47 m from the inlet end. Since the thermocouples used to measure the air temperature in the pipe were not shielded, there would be a small error in the air temperature measurement because of infrared radiative transfer between the thermocouple and the pipe surface and line voltage drop between measuring point and display. To measure soil and pipe surface temperatures, the thermocouple was positioned in the soil at the 25.6 m length of the pipe. Air velocity in the pipe measured about 1 m from the entrance; these measurements were subject to error because of entry length. To minimize the errors, air velocity was measured at four different points and then averaged. It can be seen from Fig. 3, EAHE is a closed loop and it was well isolated in terms of possible air leaks from pipe flanges. The EAHE inlet and outlet, greenhouse air temperatures and humidities were measured by means of multi channel cable free thermo-hygrometer and TESTO 6621 air conditioning transmitter. The measurement of the surface temperatures of glass reinforced plastics (GRPs) greenhouse was performed with infrared thermometer. The measurement and monitoring on a LCD display of instantaneous power consumption of the blower was made by using electronic energy analyzer.

Fig. 4 presents the measured hourly average variations of temperature of the sink—the soil at 3 m depth—and its average value was found to be 25.15 °C. It can be seen that, the inlet temperature of the air was increased average from 18.67 to 24.76 °C for an air volumetric flow rate of 3600 m^3/h. The average temperature difference of the air between the inlet and outlet of the underground air tunnel was obtained to be approximately 6.09 °C. The average heating capacity of the system was determined to be 7.67 kW for this experimental period. The temperature of the air and the pipe surface at various lengths of pipe, the inlet and outlet temperatures of the air were recorded by data logger at 1 min intervals for 12 h [32].

The experimental cooling performance studies were realized by using same experimental set up. The maximum average temperature difference of the air between the inlet and outlet of the

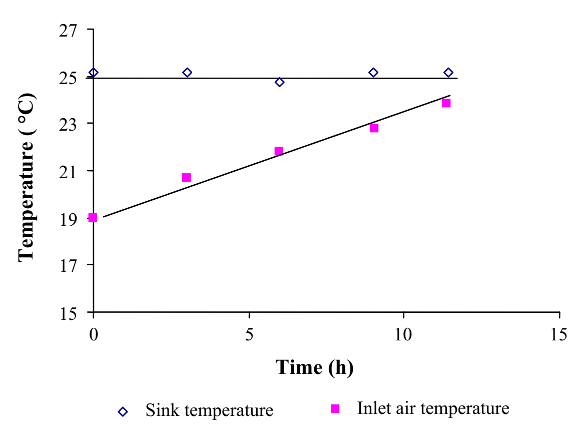

Fig. 4. Hourly average variations of the sink—soil at 3 m depth—and inlet air temperatures of EAHE for 0.28 m radii during the heating period.

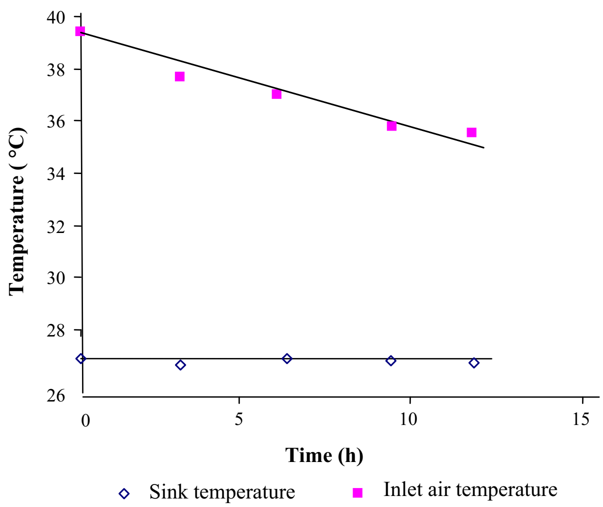

Fig. 5. Hourly average variations of the sink—soil at 3 m depth—and inlet air temperatures of EAHE for 0.28 m radii during the cooling period.

underground air tunnel was obtained to be approximately 5 °C. The maximum cooling capacity of the system was determined to be 16.93 kW for this experimental period. The temperature of the air and the pipe surface at various lengths of pipe, the inlet and outlet temperatures of the air were recorded by data logger at 1 min intervals for 12 h [4,29]. Fig. 5 presents the measured hourly variations of temperature of the soil at 3 m depth, and it's average value was found to be 27.4 °C. The temperature of the air was reduced from 39.8 °C to 34.8 °C for an air volumetric flow rate of 5300 m^3/s [28,30].

5. Conclusions

Solar energy accumulated in the soil may be utilized with an earth-to-air heat exchanger (underground air tunnel) [1–43,59,62–74]. Energy savings are of major concern everywhere. To save energy by preheating air for heating and by precooling air for cooling of residential and agricultural buildings, design, modeling and testing of underground air tunnel systems are very important. Because, UAT systems provide greenhouse gas emission reductions, installed electric power reductions, and CFC–HCFC utilization reductions, etc.

Heat pumps, GSHPs, especially EAHE systems, are recognized to be outstanding heating, cooling systems, and have been widely used for years. Most of the growth of these systems occurred in the United States and Europe. These systems have also been in use by combining other renewable energy technologies such as solar, wind energy. It may be concluded that the effective use of EAHE systems with suitable technology in the modern locations will play a leading role not only Turkey but also on the world in the foreseeable future. Furthermore, the results can draw an engineers and architects attention towards the components where the most availability is being destroyed and quantify the extent to which modification of one component affects, favorably or unfavorably, the performance of other components of the system. In this regard, it is expected that the review presented here will be very useful to the investigators dealing with passive building heating and cooling applications, especially EAHE systems.

Acknowledgement

The author would like to thank Dr. O. Ozgener due to his pre review in getting such constructive comments to help him improve the quality of the paper.

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